Soil compaction effect on surface runoff generation

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Processes, controling factors and consequences for floods

General considerations
Processes
Controlling factors
Consequences for floods
Conclusions

Abdallah Alaoui
Universität Bern

ERC Symposium I 21.10.2014 I Vienna

Land Use Changes Impacts on Floods I Session: Impacts of Soil Compaction on Floods

Runoff
Including deep circulation.
Long time period

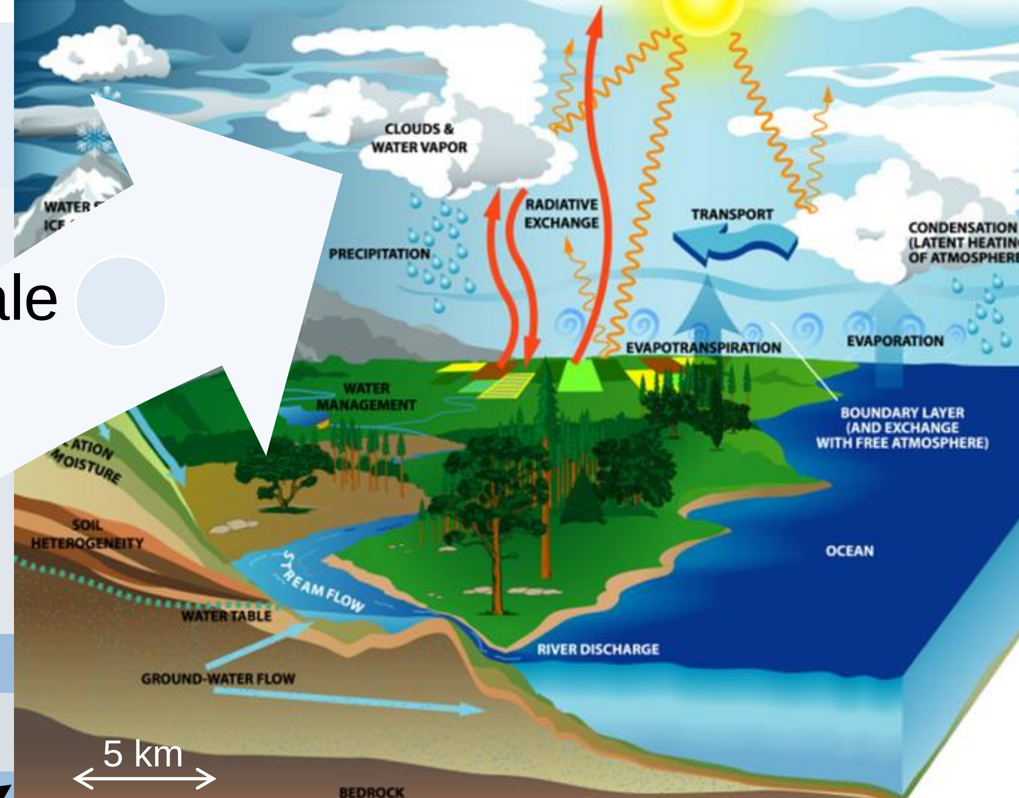
Surface runoff
0–10 cm depth.
Extreme events

Catchment scale

Hillslope scale

Plot scale

Pore scale



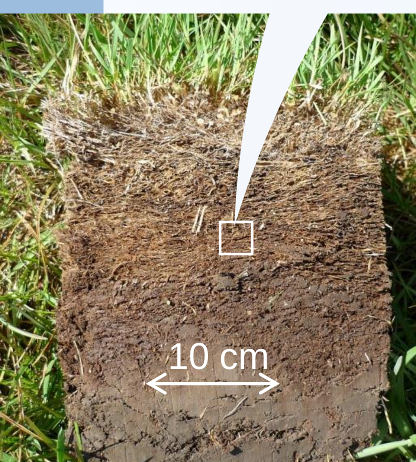
Mi

1 cm^2

Hydrological classification

Area

cs

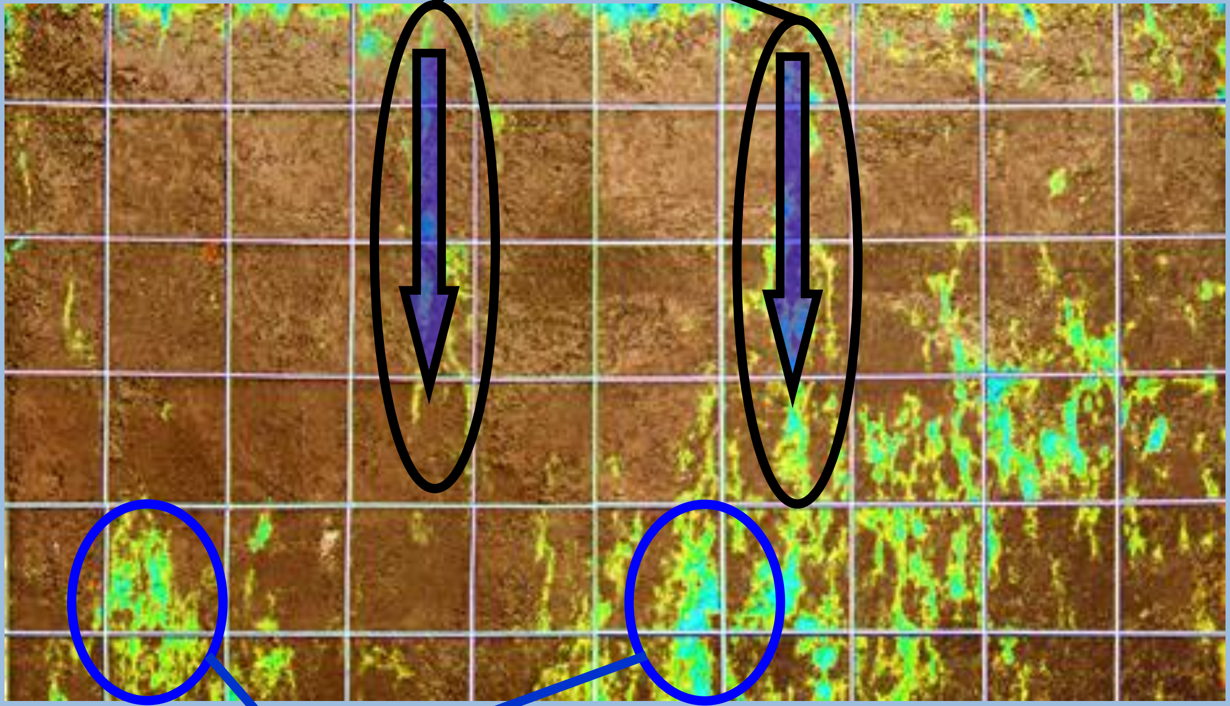


Oensingen, Kanton Solothurn
Eutric-Stagnic Cambisol
Silty clay - *Grassland*

Macropore flow
Beven & Germann (1982)

Macropores
> 30μm

Macropore volume: 0.23 – 3 %
→ 74 – 100 % of total water flow



10 cm

Matrix flow
Richard (1931)

Micropores (matrix)
< 0.2μm

Alaoui & Goetz
Geoderma , 2008

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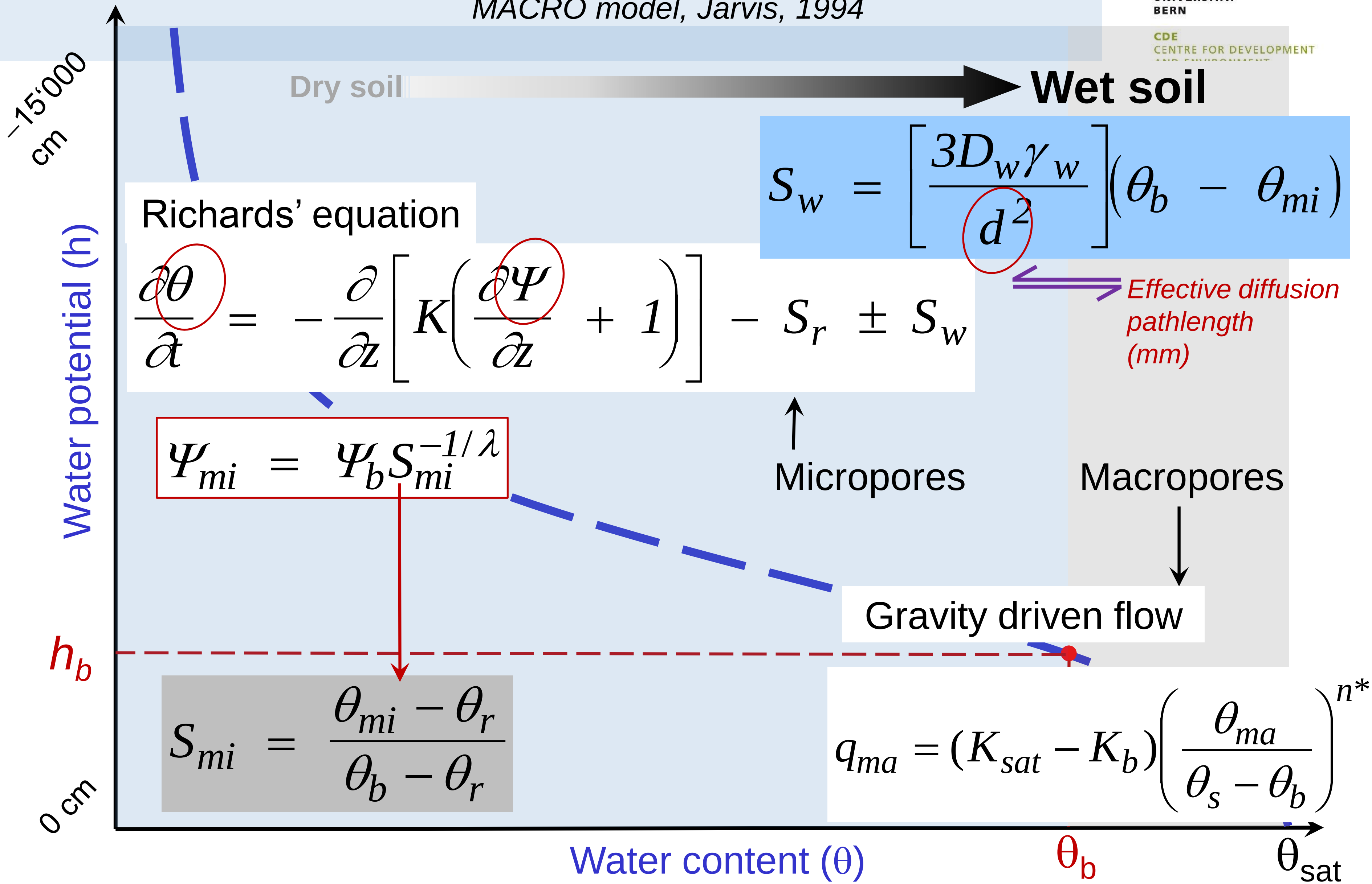
Water Retention Curve

MACRO model, Jarvis, 1994



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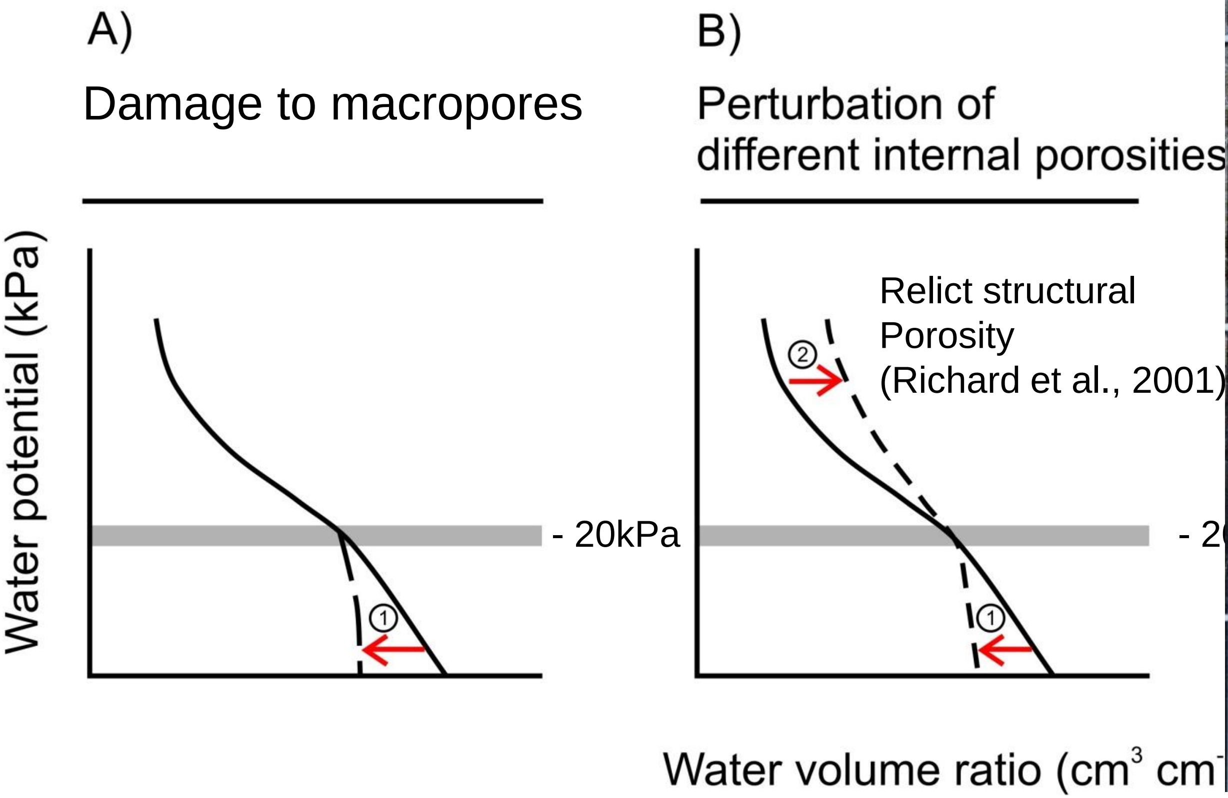
Conceptual model

Impact of land use on the Water Retention Curve



Compaction	Compaction & shearing	Trampling
Wheeled machines	Wheeled and tracked heavy machines	Pastures

Alaoui, Lipiec & Gerke – Soil & Till. Res., 2011

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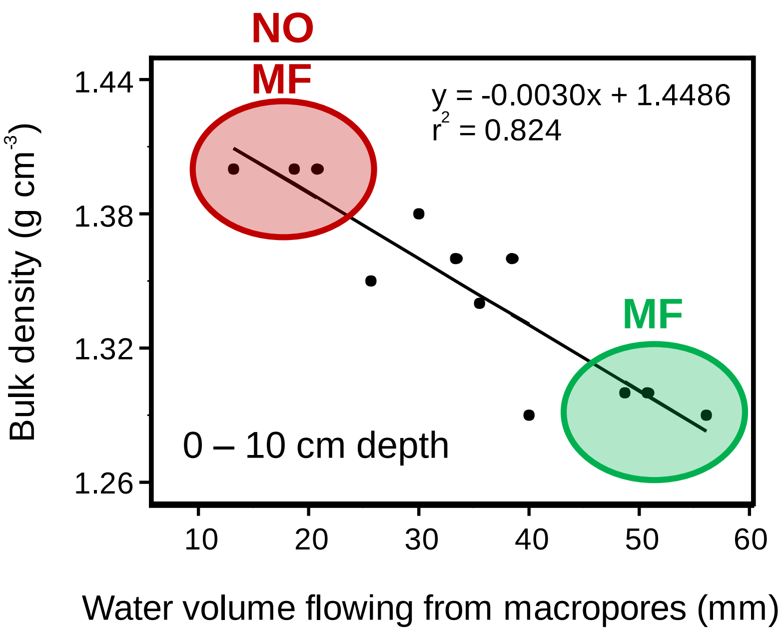
Plot scale
Controlling factors of macropore flow in grassland

40 irrigation experiments



(MF = Macropore Flow)

Strength of macropore flow ↔ Water flowing from macropores during the irrigation (MACRO model, Jarvis 1994)

Alaoui, J. Hydrol., 2014 (submitted)

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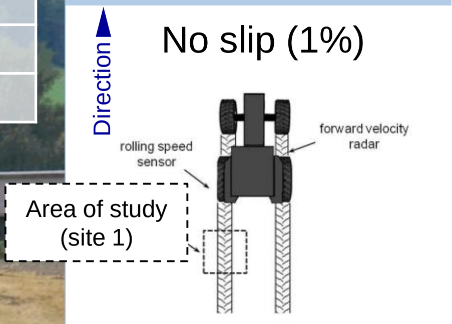
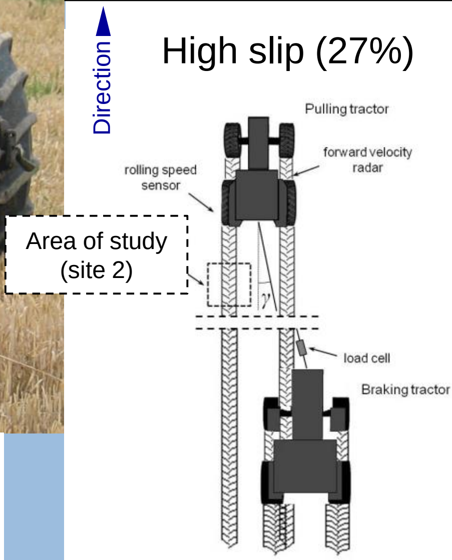
Effect of mechanical stresses acting on the interface soil-tyre during slip on the pore system and the water dynamics

Braking tractor	Massey Ferguson 8470
Power (kW)	250
Weight (kN)	90.6

Pulling tractor	Hürlimann H488 DT
Power (kW)	65
Weight (kN)	40





Normal stress increased with slip from 90.6 kPa to 104.4 kPa at topsoil, **shear contact stress** rose noticeably for both front (from 19.7 kPa to 42.6 kPa) and rear wheel (from 6.0 kPa to 61.6 kPa)

Battiato et al., 2014, in prep.

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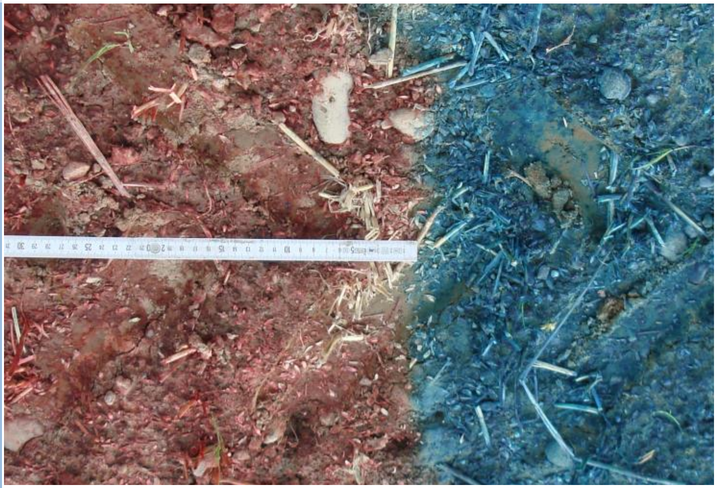
a) Trafick without slip (site 1)



b) Trafick with slip (site 2)

| 0 m → 0.35 m

- Decreases total porosity by **11 %**, macroporosity by 60 %, and K_{sat} by 97 %.

Decreases total porosity by **89 %**, macroporosity by about 95 %, and K_{sat} by 98 %.

Measurements

- Loss in water (topsoil macropores) decreases by **30 %** from site 1 to site 2.

Rainfall intensity = 100 mm h^{-1} (1 hour)

- Runoff coefficient = **0.79**

Runoff coefficient = **1.00**

Erosion and floods

Measurements (Plot of 15 m^2, 15°) & Modelling

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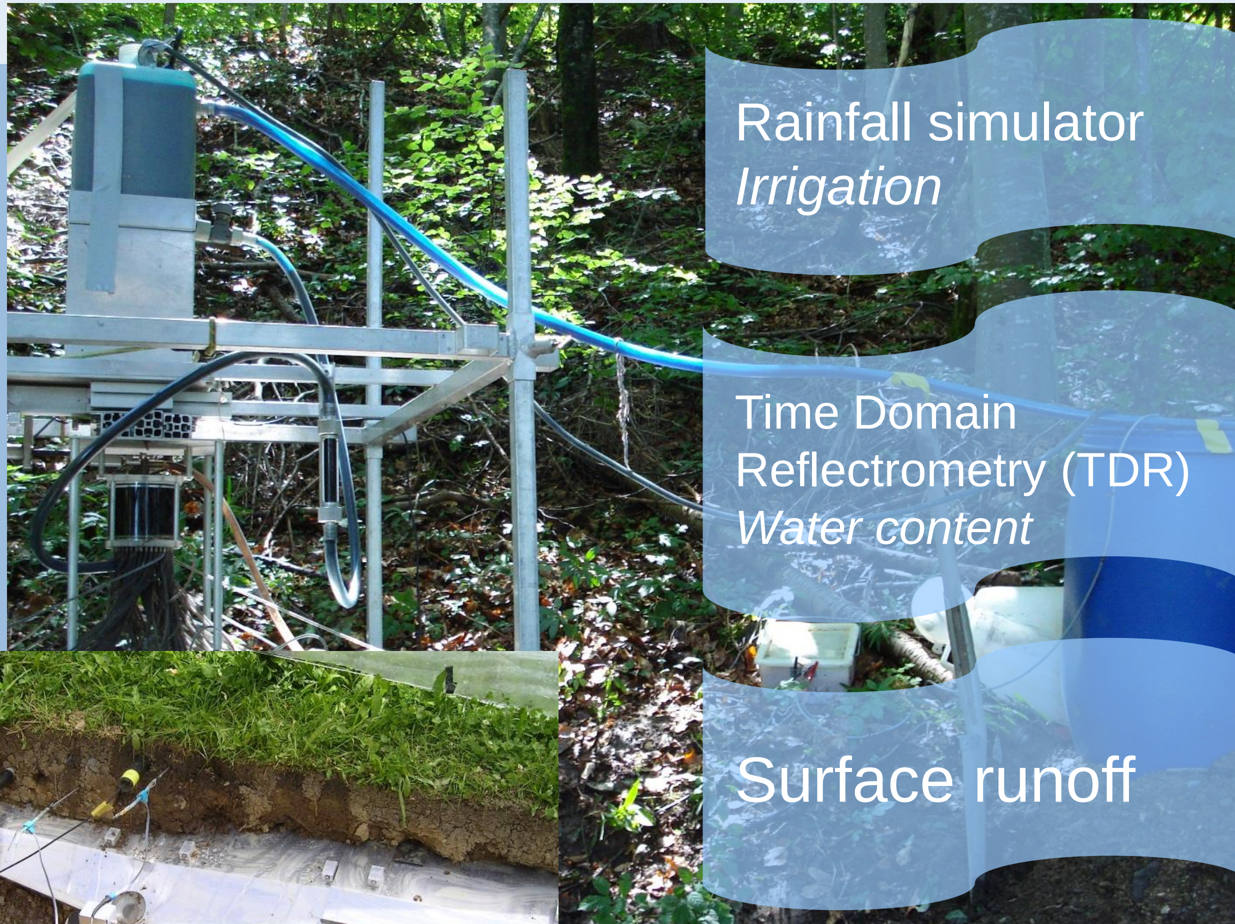
Hillslope

Experimental setup



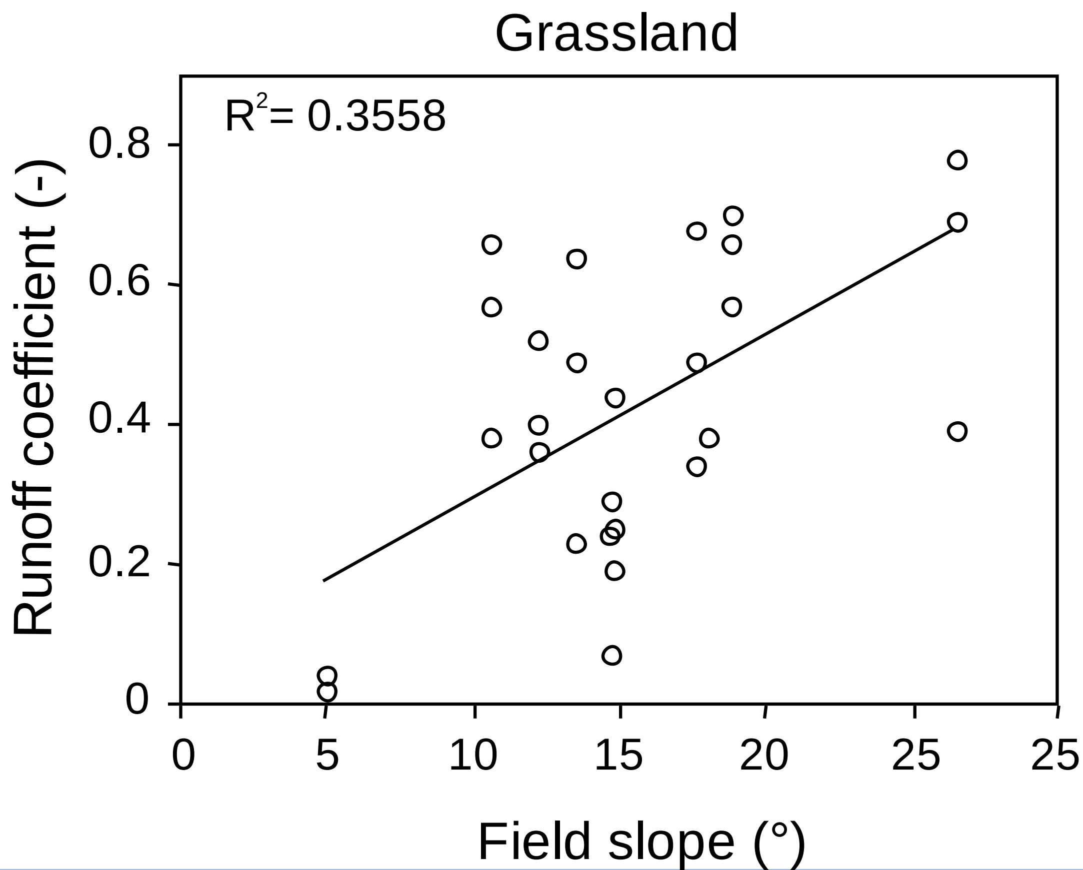
Rainfall simulator
Irrigation

Time Domain Reflectrometry (TDR)
Water content

Surface runoff

Hillslope

Results



Runoff coefficient (RC) vs. field slope in grassland soils for three different intensities (24, 36, and 48 mm h^{-1}).

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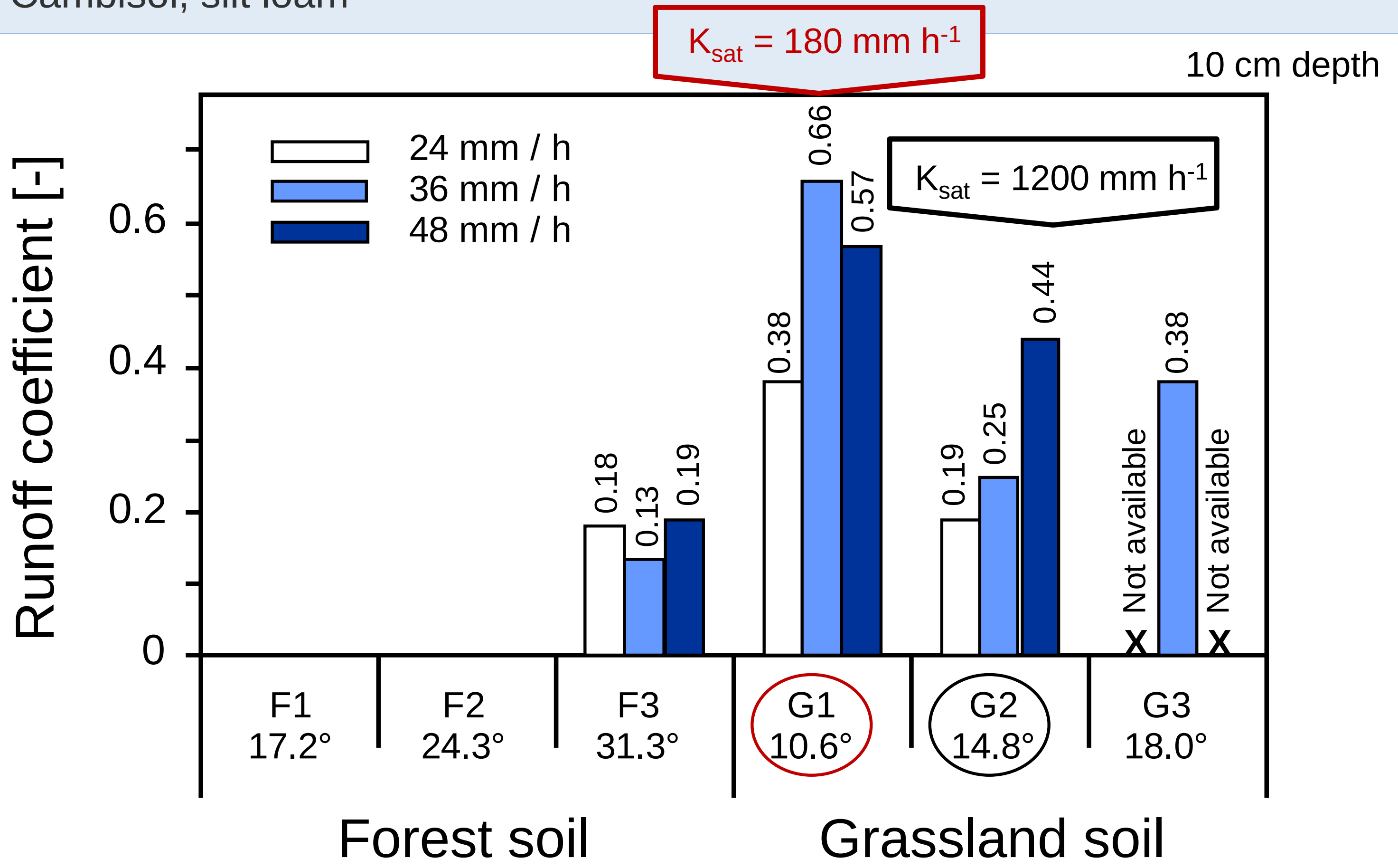
Hillslope

Kandergrund, Kander Valley
Cambisol, silt loam

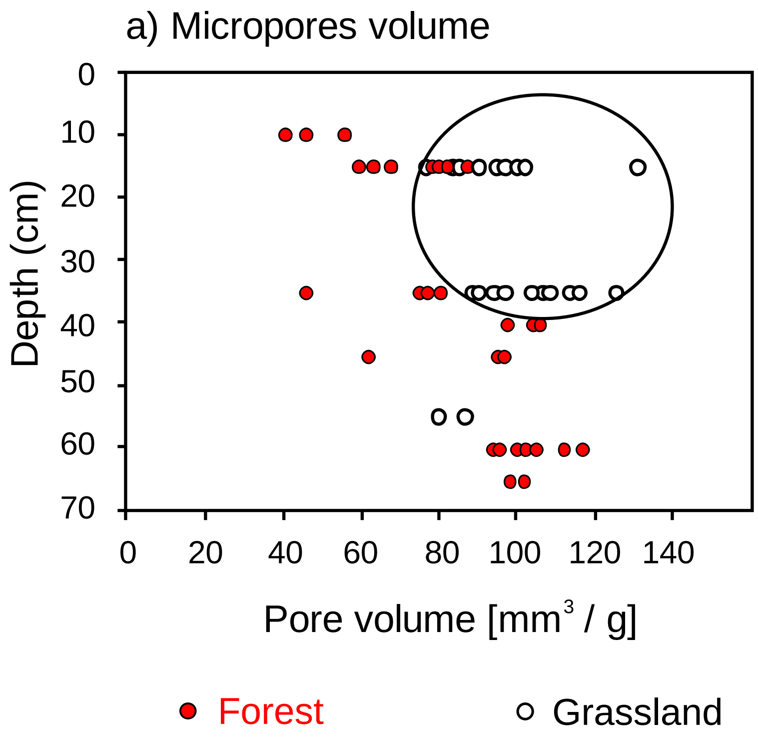


Runoff coefficient (RC) of the plots in forest and grassland soils for different slopes and intensities (24, 36, and 48 mm h^{-1})

(Alaoui et al., 2011, VZJ)

Hillslope

Kandergrund, Kander Valley
Cambisol, silt loam



Investigation of topmost 10 – 15 cm in grassland hillslopes

(Alaoui et al., 2011–VZJ)

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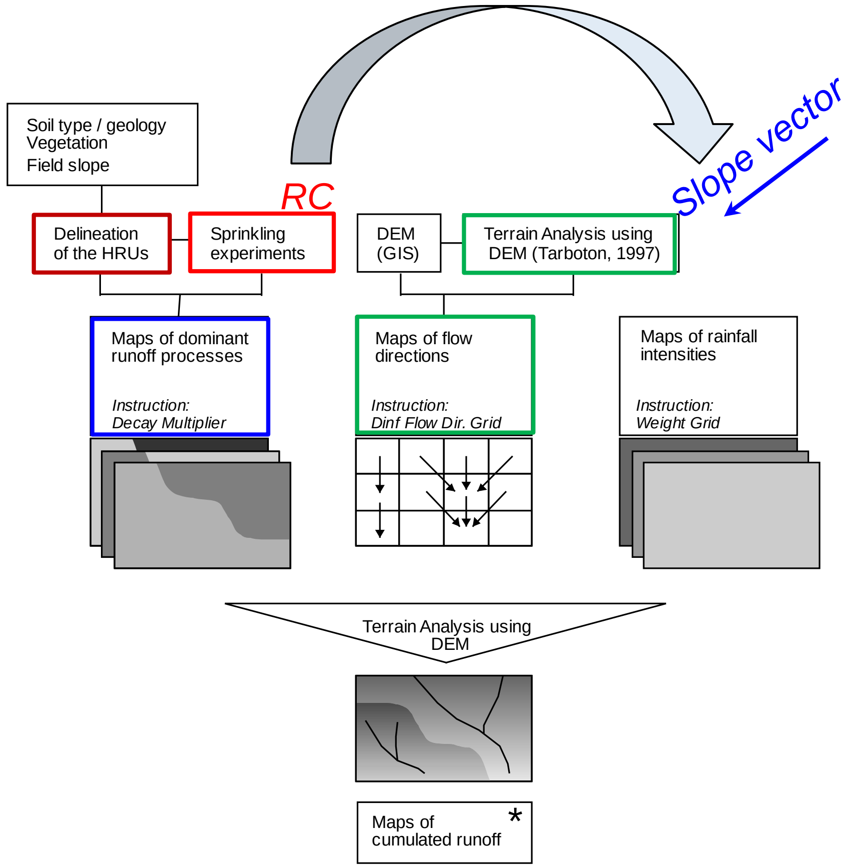
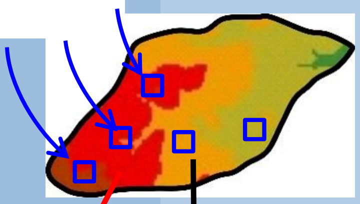
Catchment



Steps to realize maps of cumulated runoff
*time is not considered

Sprinkling Experiments (60x)



HRU-2

HRU-1

Slope class 1 ➔ RC1
Slope class 2 ➔ RC2
Slope class 3 ➔ RC2

Slope class 1 ➔ RC1
Slope class 2 ➔ RC2
Slope class 3 ➔ RC3

Alaoui et al. (Hydrology Research, 2012)

Catchment

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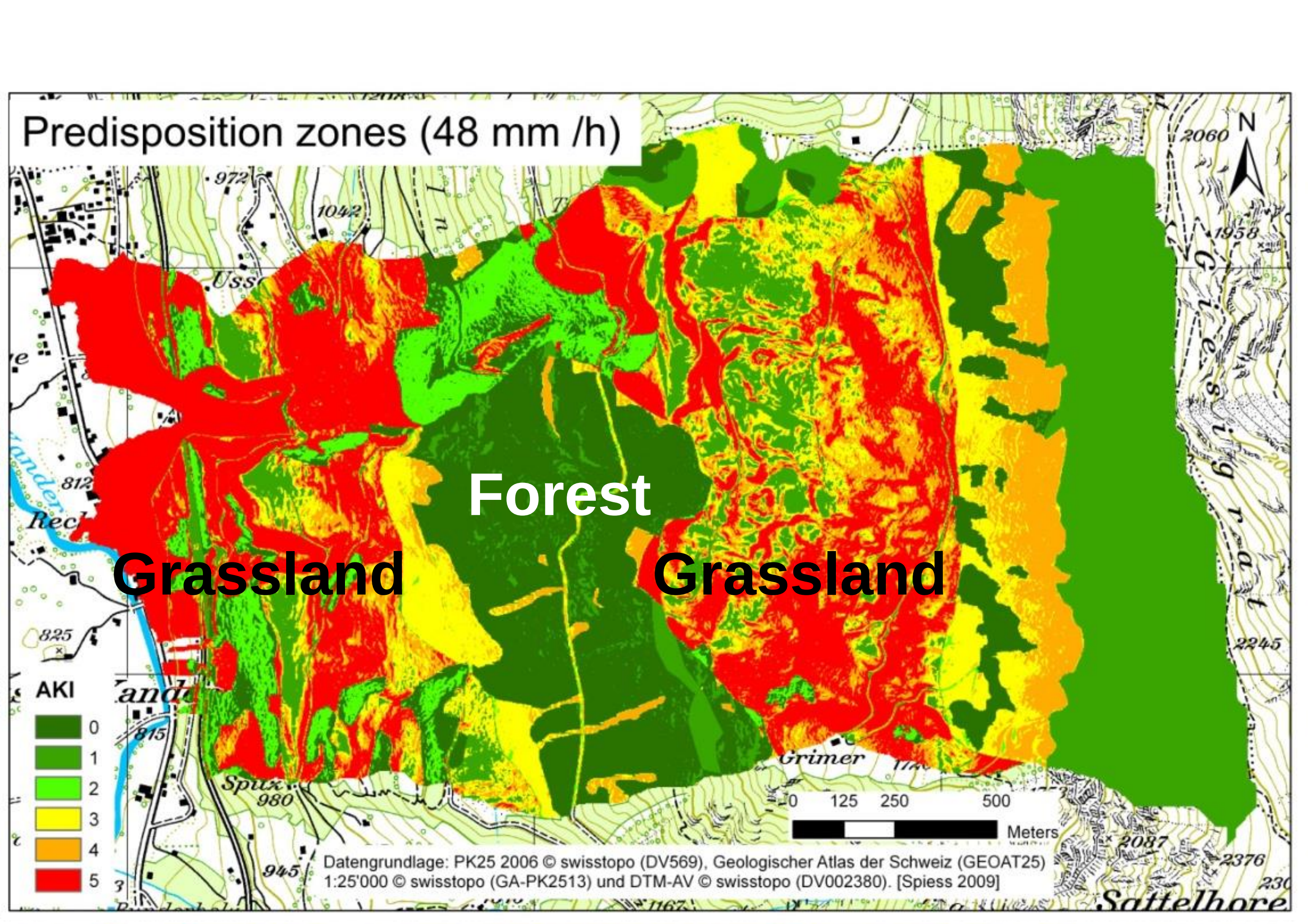
Up-scaling runoff processes (TauDEM*)



*Tarboton, 1997, WRR

Alaoui et al. (Hydrology Research, 2012)

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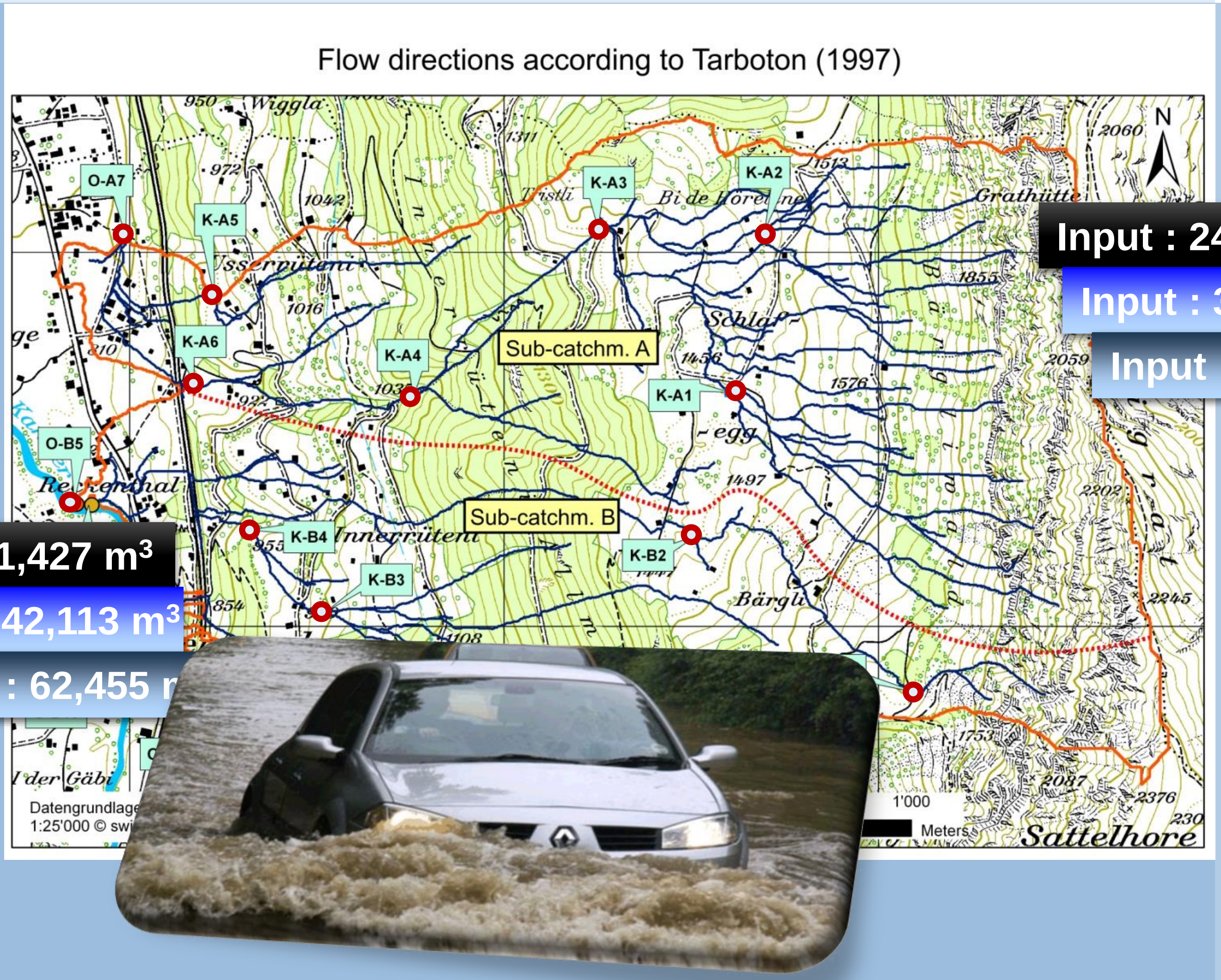
Catchment

Flow directions (TauDEM)



Input : 24 mm / h
Input : 36 mm / h
Input : 48 mm / h

Output : 21,427 m³
Output : 42,113 m³
Output : 62,455 m³

Alaoui et al. (Hydrology Research, 2012)

Catchment (200 km²)
Central Swiss Alps, Ursern Valley (TauDEM)

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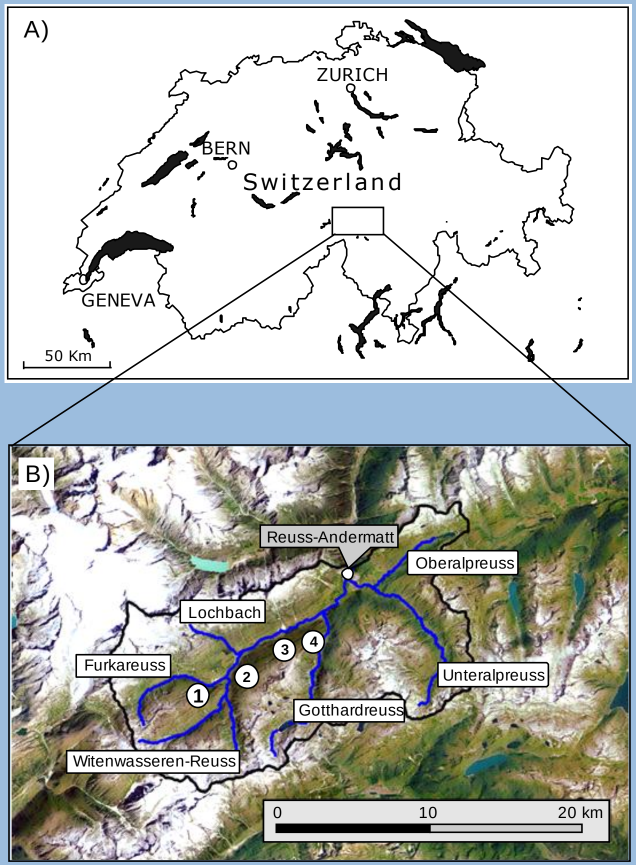


Surface area: 200 km²
Elevation: 1400 to 3600 m a.s.l.
Mean annual P. = 1900 mm
Mean annual discharge = 1540 mm
Grassland = 65%

1965 – 1994, area covered by **green alder** increased by **32 %**
Glacier = 3.7 %

The main aim was to examine the impact of **land use** (i.e. expansion of green alder) and **climat changes** (i.e. snowmelt and glacier discharge) on hydrology (1983 – 2005)

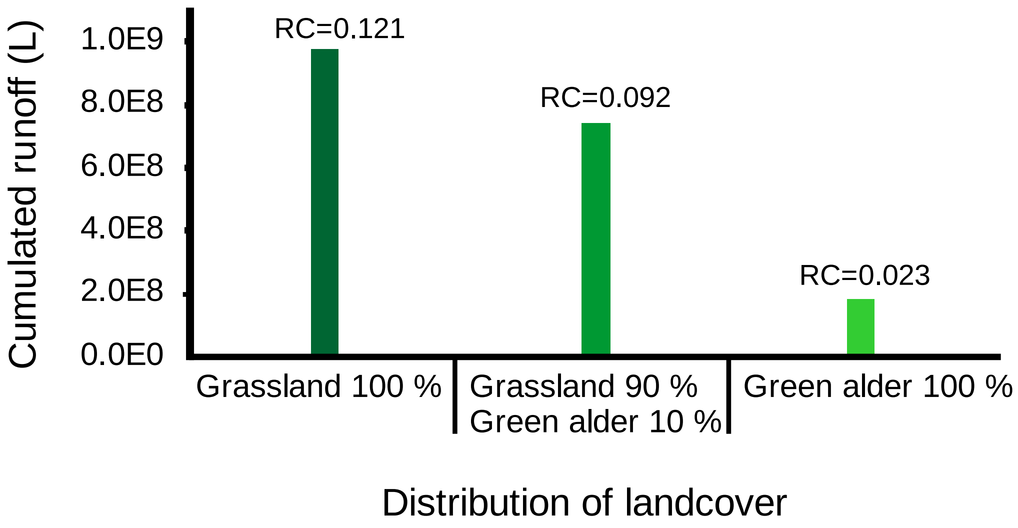
Modelling the Effects of Land Use and Climate Changes on Hydrology

Alaoui et al., 2014, Hydrol. Processes

Catchment (200 km^2)

Central Swiss Alps, Ursern Valley (TauDEM)

Extreme event



Modelling **cumulated runoff** in final outlet of entire catchment for different scenarios

Impact of Land Use on discharge

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Catchment (200 km^2)

Central Swiss Alps, Ursern Valley (TauDEM)

Water balance (1983 – 2005)

	WaSiM-ETH				
Scenarios	**Grassland (%)**	**Green alder (%)**	**Bare soil (%)**	**Other (%)**	**Ice /glaciers (% / km^2)**
PLU_PC / PLU_FC	74	0	22	4	3.7 / 7
CLU_PC / CLU_FC	65	9	22	4	3.7 / 7
FLU_PC / FLU_PC	52	24	22	2	3.7 / 7

Effect of Land use on yearly discharge (Q)	**Effect of climate change on yearly discharge (Q)**	**Combined effect on yearly discharge (Q)**
$\mathbf{Q_{(FLU\_PC)} - Q_{(PLU\_PC)}}$	$Q_{(FLU\_FC)} - Q_{(FLU\_PC)}$	$Q_{(FLU\_FC)} - Q_{(CLU\_FC)}$
-0.027 mm (- 0.6%)	-0.203 mm (-1.7%)	-0.221 mm **(- 5%)**
		WaSiM model, Schulla, 2012

Impact of Land Use and Climate Changes on Hydrology

Alaoui et al., 2014, Hydrol. Processes

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Conclusions

> The marked differences in the **textural and structural porosities** between forest and grassland plots appear to control runoff processes.

> **Forest** soil has a higher storage capacity than grassland soil that promotes vertical water flow and prevents surface runoff.

> Dense soil due to **compaction** present in the topmost ten centimeters was found to exert <u>predominant control</u> on surface runoff.

> **Up-scaling** runoff processes using TauDEM based on irrigation experiments gave more quantitative insight into flow processes such as flow directions and runoff.

Miracles Maps of the predisposition to floods